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Title: Slide Test FY 2019 Report

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Executive Summary

At Los Alamos, the Slide Test was developed in 2019 to investigate whether the mass of a main charge of explosive sliding on a gritty surface, in the absence of impact, is sufficient to heat grit to ignition temperatures in PBX 9501. This is a practical test to address frictional ignition during assembly/disassembly operations at the Pantex Plant.

Twenty-seven Slide Tests were performed in total, testing PBX 9501 at various slide velocities, grit diameters, grit patterns, and charge masses. Time-resolved velocimetry of the slide event (from PDV) and spot area of the explosive charge (obtained from image analysis) is reported. High-speed videography is used to diagnose explosive reaction. Eighteen of these tests were performed with a charge mass of 30 lbs at velocities ≤ 4 m s^{-1} and grit diameters between 75 and 1000 µm. Nine Slide Tests were performed with a 15 lb charge mass at similar parameters. No ignition was observed in any of the tests.

These data provide evidence that the mass of a main charge, caused to slide on a surface at the low velocities achievable during routine handling, is insufficient stimulus to heat grit to ignition temperatures. These findings are relevant to risk assessment for explosive handling operations and provide evidence that PBX 9501 is safe within the constraints that were tested. However, because ignitions were not observed in any of the tests, we cannot determine which variables (mass or velocity) dominate the explosive response and to what extent. The absence of observed ignition also precludes the determination of a safety margin. To identify this safety margin, further research would be necessary to define the velocity and/or mass threshold at which ignition occurs.

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1. Introduction

Dropped high explosive (HE) charges have been implicated as the cause of multiple deadly historical accidents. Skid Testing experiments validated this mechanism for dynamic impacts on grit-contaminated surfaces[1]. Those results raised an additional question: can ignition, or more violent responses be achieved merely by sliding an explosive charge on a grit-contaminated surface? Is a dynamic impact required for an explosive reaction?

Dyer and Taylor[2] observed explosions when explosive was subjection to frictional ignitions, but only when sufficient static pre-load pressure was applied to the charge. However, at the time of their experiments (1970) they lacked the technology to diagnose ignition sites that might occur and quench in low pressure experiments. Their results do not provide sufficient data to determine whether the mass of a main charge alone is sufficient pressure for an explosive to reach ignition temperatures when being slid on a frictional surface without impact.

Two ignition mechanisms of low-velocity mechanical impacts of conventional secondary high explosive are known to exist: shear/viscous heating internal to the explosive and frictional heating of two high-melting point materials that are in contact with the explosive. Shear/viscous heating is caused by rapid crushing deformations. The conditions for this ignition mechanism are not present in the Slide Test, where no dynamic impact occurs. Frictional heating of two high-melting point materials that are in contact with the explosive can cause ignition at very low impact velocities[3]. This mechanism was originally reported in Dyer and Taylor[2], was thoroughly explored in Skid Test research [1], and is the potential ignition mechanism relevant to the slide insult investigated in this report.

2. Prior Frictional Ignition Research

Initiation by friction of a high explosive charge was first experimented by Dyer and Taylor and published in 1970[2]. Dyer and Taylor experimented with a variety of testing parameters, including the presence and absence of loose grit, frictional surfaces, applied pressures, velocities, explosive types and explosive sizes. They tested initiation by friction both with and without an oblique impact.

Dyer and Taylor's apparatus was designed to test frictional ignition of explosives without oblique impacts by sliding a frictional surface in a lateral direction (normal to the gravitational force) at a constant velocity. They used an HMX/TNT explosive composition (98% HMX, 2% TNT) for the majority of their frictional ignition tests, and two sizes of explosive cubes were tested: 1 in and 0.5 in. The friction surfaces used included sand coated steel strip (251-295 μm grit diameter), single grit (300 μm diameter), sheet glass, slab of HE, and a thin metal file. Various grit dispositions and patterns were tested. Their first experiments were comprised of a resting 100 lb mass on top of the explosive assembly. This mass created a reported contact pressure of approximately 690 kPa between the explosive and the frictional surface. Velocities between 1.5 and 6 m s^{-1} were tested. They did not observe any explosions in these tests and the results were reported as a non-explosive event. However, they did observe occasional "puffs of smoke" even though ignition was not reported[2]. They advanced to a pneumatic preloading piston to apply additional pressure to the explosive assembly, drastically increased the contact pressure to a range of 2.3 to 50.3 MPa. The minimum contact pressure at which explosions were observed was 8 MPa. Because Dyer and Taylor reportedly observed "puffs of smoke" in their low pressure tests, we hypothesize that this gas was caused by grit reaching ignition temperatures. Dyer and Taylor lacked the technology to directly observe these ignition sites, prohibiting them from accurately reporting ignition.

Dyer and Taylor's work provided a foundation of knowledge for frictional ignition mechanisms of high explosive. However, their diagnostics consisted of a relatively crude go, no/go criterion dependent on the magnitude of a violent response (puffs of smoke do not reliably diagnose ignition sites; this was confirmed in the Skid Test[1]). With the diagnostics available at the time, Dyer and Taylor were unable to characterize the details of the explosive response in the regime between insult and explosion. The "ignition time" in modern parlance is understood to be the onset of an ignition site, rather than violent explosion, which Dyer and Taylor were unable to observe.

Dyer and Taylor's research left uncertainty which the modern Skid Test experiments conducted at LANL in the past decade have cleared up. With modern diagnostic methods and Skid Testing pendulum, ignition sites followed by quench have been observed at considerably lower drop heights than historically reported[4]. A gap can exist between the level of insult required to produce an ignition and that required to produce a violent reaction. An experiment that relies on violent response as criteria for a "go" result, as was the case with Dyer and Taylor, will fail to identify quenched ignitions in that gap. Ignitions even in the absence of violent explosion constitute important findings for explosive safety. The path from ignition to explosion remains difficult to predict. Consequently, the current approach to mitigate explosive handling hazards relies heavily on eliminating any potential ignition mechanism. Therefore, it is important to understand the threshold at which ignition sites can be generated (not just explosions).

3. Slide Test Experiment

The Slide Test was developed in FY19 to investigate whether the mass of a main charge sliding on a grit-contaminated surface, without dynamic loading from impact, is sufficient enough to cause explosive reaction in PBX 9501. It is essentially a modern repeat of Dyer and Taylor's work, with additional diagnostics and using explosive compositions relevant to modern handling operations with LANL CHE systems (notably, PBX 9501). Also, the pressures Dyer and Taylor used in their charge friction apparatus are unrepresentative of accidental sliding scenarios; the Slide Test was designed to explore low loading pressures in the regime of interest for handling scenarios.

4. Experiment Design

4.1. Pendulum

The pendulum apparatus from Skid Testing was modified in FY19 to provide a hammer dropping mechanism for Slide Test experiments, Figure 1. The modifications allow the pendulum arm to release an impact hammer immediately before colliding with an impact plate. The impact plate translates this momentum through the horizontal rail system, pulling the glass out from under the HE. The hammer is caught by walls secured to the strut frame, maximizing the momentum being transferred. The original pendulum design has been described in detail previously [5]; modifications and upgrades are documented in reference [6].

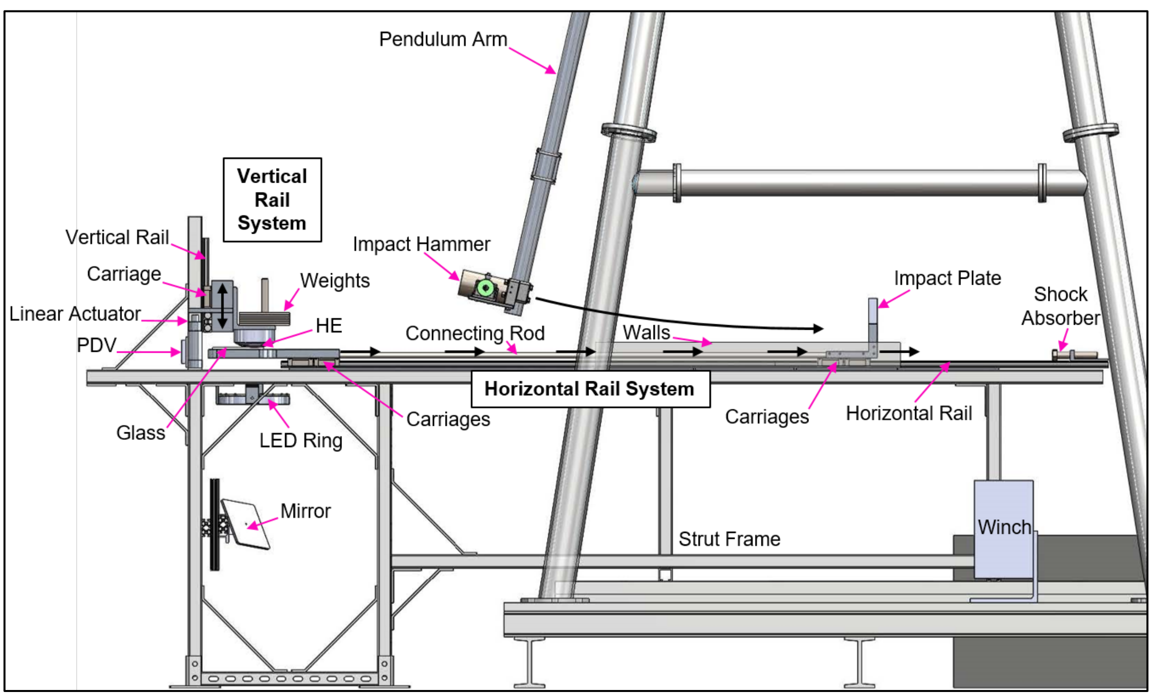


Figure 1. Slide Test pendulum assembly.

4.2. Rail Systems

The vertical and horizontal rail systems work simultaneously to slide a gritty glass sample out from under a resting explosive, Figure 2. The vertical rail system, Figure 6, is composed of a ball bearing carriage, a break, half-pound steel plates, and the explosive. The ball bearing carriage provides the system with vertical slide motion along the linear guide rail. The brake holds the assembly in a static position for mounting the explosive. The half-pound steel plates allow different charge masses to be simulated when they are either semi or fully stacked. The HE is fastened to the bottom of the vertical rail system, allowing the explosive to remain in a downward facing position. A linear actuator is fastened to the strut fame underneath the vertical rail system to lower the HE onto the glass from a remote location. The total mass of the vertical rail system, excluding the half pound steel plates, is 9.3 lbs.

The horizontal rail system, Figure 3, consist of several ball bearing carriages, a 5-foot-long steel connecting rod, the glass and glass holder, and the impact plate. The steel rod connects the impact plate to the glass and glass holder, which all slide down the linear motion guide rail together when the hammer strikes the impact plate. A piezoelectric film sensor lies between the hammer and the impact plate, triggering the diagnostics when the impact is received. A shock absorber, located at the far end of the rail, slows down the horizontal rail system when the impact plate reaches the end of the rail, Figure 42.

Table 1. CAD view of the Slide Test rail systems.

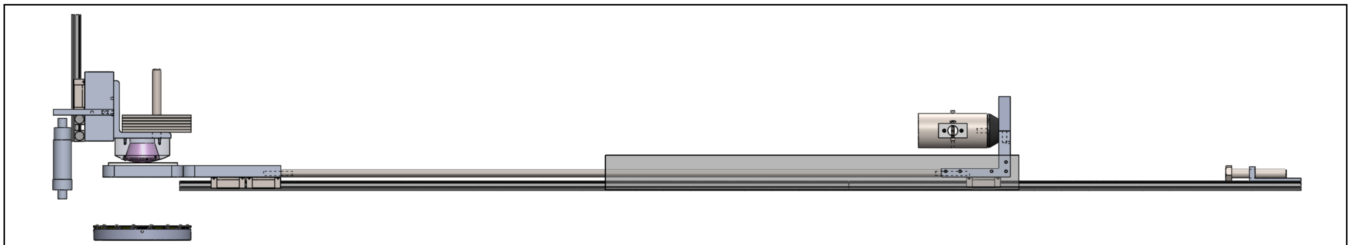


Figure 2. CAD side view of rail systems independent of strut frame.

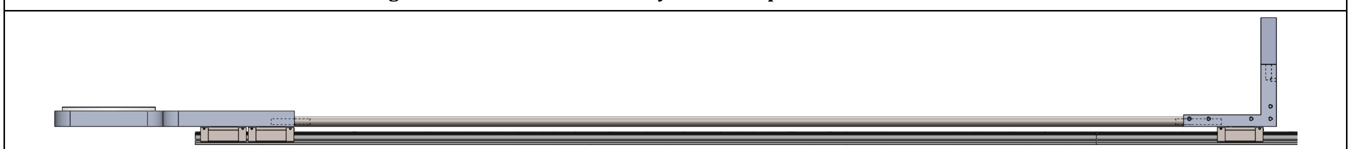


Figure 3. CAD side view of horizontal rail system assembly.

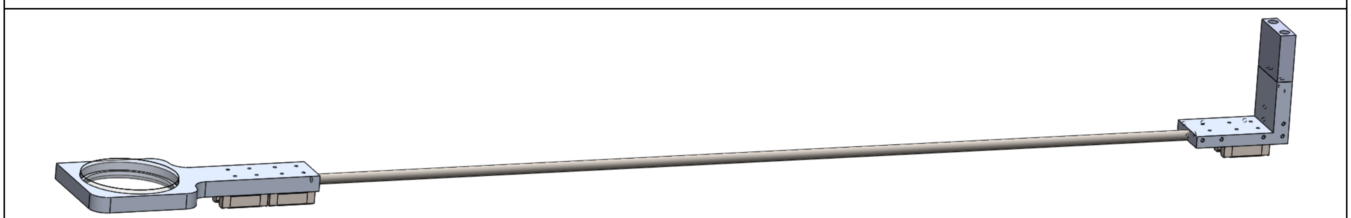


Figure 4. CAD view of horizontal rail system assembly independent of rail.

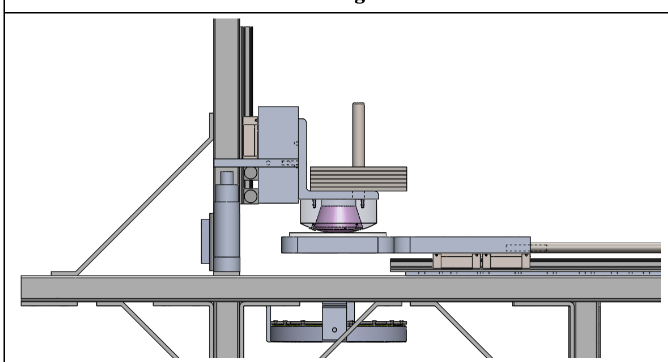


Figure 5. CAD side view of HE and glass contact.

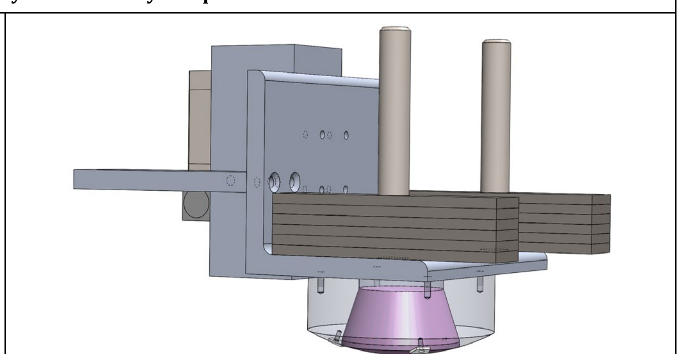


Figure 6. CAD view of vertical rail system assembly.

4.1. Slide Surface

Unused cylindrical glass samples (soda lime) from early Skid Tests were used in combination with sand to simulate a grit-contaminated surface. We commonly use glass in frictional ignition testing as an analog for gauge blocks or concrete flooring because of their similar melting points and hardness values, with the benefit of transparency for observation[7]. The glass samples are 0.75 inches thick and 6 inches in diameter, the determining length for a slide test. The length that the explosive drags on the glass is relatable to the scenario of a person moving a charge across a work surface. The same process for preparing the glass targets in Skid Testing is used[7] and each test uses an new sample of glass.

4.2. Explosive

The Slide Test uses the same "cupcake" sample geometry that was originally developed in FY13 for Skid Testing, Figure 7. The PBX 9501 cupcake has a nominal density of 1.83 g/cc and a mass of 249 g. The explosive sample is held in a small polyoxymethylene (POM) holder (generic for Delrin™). This holder is fastened below the vertical rail system. Where charge mass is reported, this includes the total mass of the vertical rail system, including any additional mass added.

Table 2. CAD images of the explosive sample.

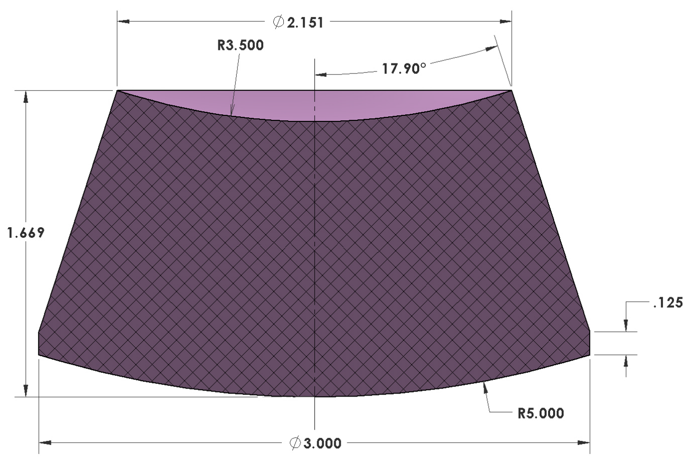


Figure 7. Explosive geometry; the "cupcake," with dimensions in inches.

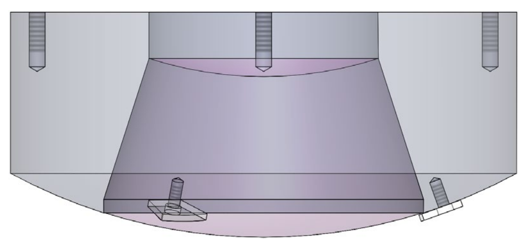


Figure 8. "Cupcake" mounted in POM holder.

4.3. Diagnostics

4.3.1. High-speed video

The primary diagnostic is a close-up view through the transparent glass with a high-speed video camera, Figure 39. A Vision Research® Phantom™, model V2512 is used with a 400 mm focal length lens at an aperture of f11 to obtain frame rates of 150,000 fps at a resolution of 384 px by 288 px. A custom-built LED light ring is mounted below the glass to provide the considerable illumination required for a well-exposed image at this frame rate. The LED lighting is turned on just before the test, and off just afterwards, in order to avoid overheating the LED elements (the custom ring is designed only for intermittent rather than continuous duty use).

A second high-speed video camera is used to record a wide side-view of the tests, providing a record of possible explosion.

4.3.2. Velocimetry

The primary diagnostic for velocity is a photon Doppler velocimetry (PDV) system Figure 43. This system records velocity data of the glass sample as it gets pulled out from under the explosive.

5. Results

5.1. Summary

Slide Test FY19 was executed October 2019 in Los Alamos, NM where the average humidity for the month was 1% and the daily average high temperature was 50 ºF (10 ˚C). The data for this test series are summarized in Table 3.

Twenty-seven Slide Tests were performed with PBX 9501 at two different charge mass simulations: 30 lbs and 15 lbs. Eighteen of these tests were performed with the 30 lb charge mass and nine were performed with the 15 lb charge mass. A variety of low velocities and grit diameters were tested with each charge mass, including: velocities 1 m s^{-1}, 2 m s^{-1}, 3 m s^{-1}, and 4 m s^{-1}; and grit diameters of 75-150 µm, 150-250 µm, 250-500 µm, and 500-1000 µm. Ignition was not observed in any of the tests (Table 3). The results are summarized in Figure 9.

We attempted to reach higher velocities in order to observe an ignition threshold. However, the maximum velocity of the apparatus was limited by the structural strength and friction of the horizontal linear motion guide rail. The highest attainable velocity reached was 4.15 m s^{-1}. The pendulum arm was raised to larger heights in tests 025, 026, and 027 to attain higher velocities, but the friction from the grease on a replaced ball bearing carriage prevented the horizontal rail system from attaining predicted velocities, Table 3.

Table 3. Test details and results for FY19 Slide Test study.

Slide Test #	Impact Surface (Glass)	Predicted Velocity (m/s)	PDV Velocity (m/s)	Charge Mass (lbs)	Drop Height (ft)	Grit Size (µm)	Result
001	Full Grit	2.5	N/A	15	3'	250-500	No Ignition
002	Full Grit	3.72	N/A	30	6'	250-500	No Ignition
003	Full Grit	4	4.12	30	6' 4.3"	250-500	No Ignition
004	Full Grit	4	4.15	30	6' 4.3"	250-500	No Ignition
005	Half Grit	4	4.00	30	6' 4.3"	250-500	No Ignition
006	Half Grit	4	4.09	30	6' 4.3"	250-500	No Ignition
007	1 Embed Grit	4	N/A	30	6' 4.3"	250-500	No Ignition
008	1 Embed Grit	4	4.12	30	6' 4.3"	250-500	No Ignition
009	4 Embed Grit Pattern	4	4.03	30	6' 4.3"	250-500	No Ignition
010	4 Embed Grit Pattern	4	4.06	30	6' 4.3"	250-500	No Ignition
011	Full Grit	4	4.10	30	6' 4.3"	500-1000	No Ignition
012	Full Grit	4	3.99	30	6' 4.3"	150-250	No Ignition
013	Full Grit	4	4.01	30	6' 4.3"	75-150	No Ignition
014	Full Grit	3	3.00	30	3' 8.6"	250-500	No Ignition
015	Full Grit	2	2.07	30	1' 9.3"	250-500	No Ignition
016	Full Grit	1	1.08	30	6"	250-500	No Ignition
017	Full Grit	4	4.05	15	6' 4.3"	250-500	No Ignition
018	Full Grit	3	2.93	15	3' 8.6"	250-500	No Ignition
019	Full Grit	2	2.08	15	1' 9.3"	250-500	No Ignition
020	Full Grit	1	1.52	15	6"	250-500	No Ignition
021	Full Grit	4	3.98	15	6' 4.3"	500-1000	No Ignition
022	Full Grit	4	4.03	15	6' 4.3"	150-250	No Ignition
023	Full Grit	4	N/A	15	6' 4.3"	75-150	No Ignition
024	5 Embed Grit Pattern	4	2.49	15	6' 4.3"	250-500	No Ignition
025	5 Embed Grit Pattern	5	4.06	30	9' 8.3"	250-500	No Ignition
026	Full Grit	5	3.65	30	9' 8.3"	250-500	No Ignition
027	Full Grit	6	4.08	30	13' 8.6"	250-500	No Ignition

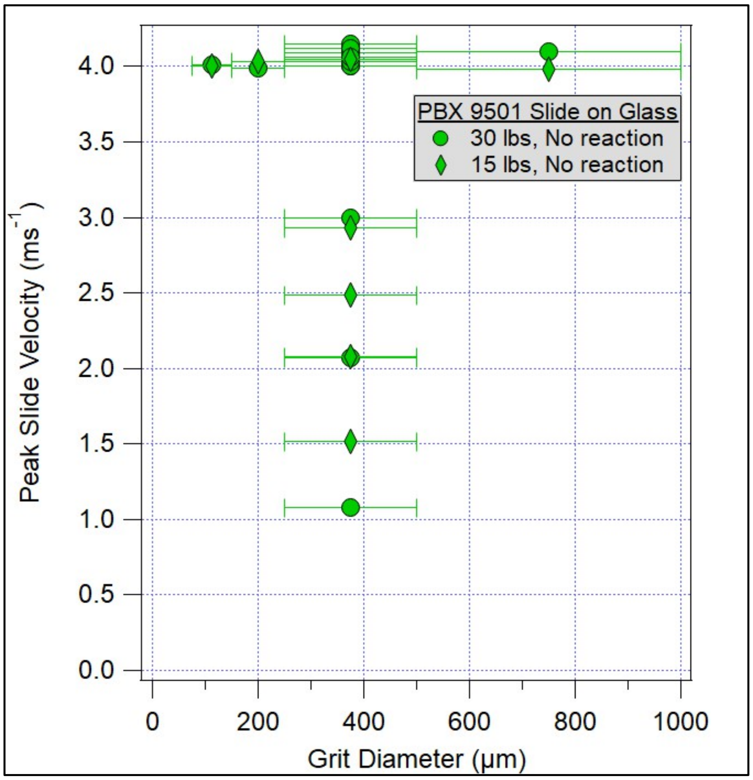


Figure 9. 30 and 15 lb charge mass Slide Test results.

5.2. Discussion

The Slide Test experiment tested frictional heating of two high-melting point materials (i.e., the surface and grit particles contaminants) in contact with the explosive at several types of low velocity insults. Figure 10 and Figure 11 show PDV data of the 15 lb and 30 lb charge weights at the four velocities tested. The reported nominal sliding velocity characterizes the peak velocity attained during the event. The peak velocity is reached by 7 ms under approximately constant acceleration. After peak, the velocity decreases slowly (<10%) over the remaining duration of the event.

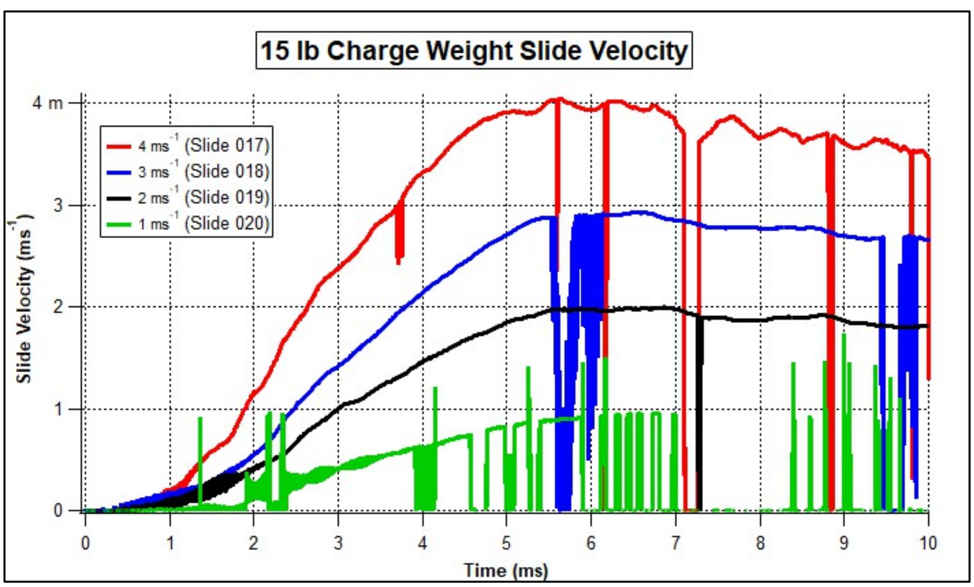


Figure 10. PDV data of 15 lb charge tests with 250-500 µm grit.

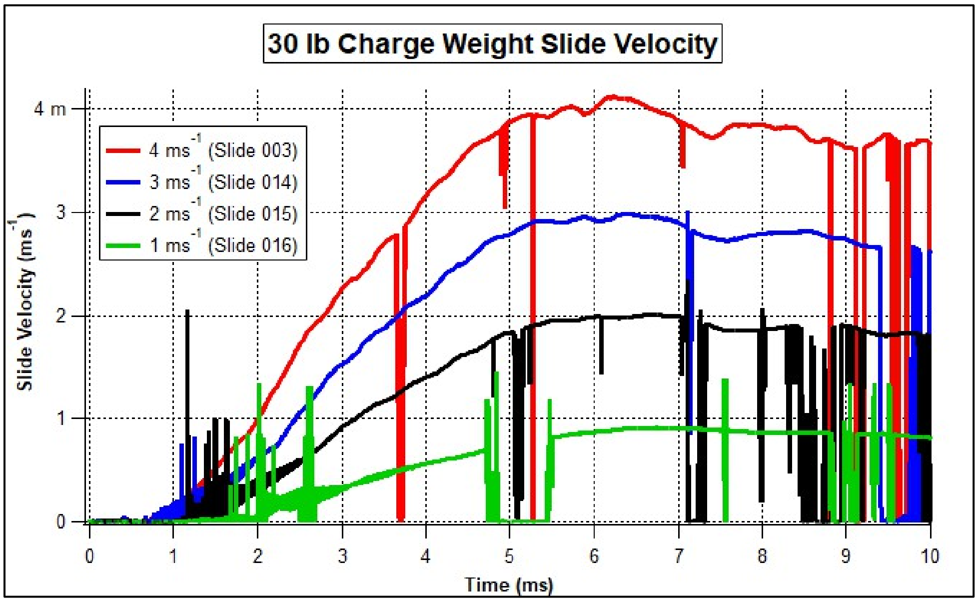


Figure 11. PDV data of 30 lb charge tests with 250-500 μm grit.

In the high-speed video, the contact between the explosive and the glass sample is sometimes evident as a darkened pressure circle, Figure 12. When the assembly mass is low, the pressure circle does not initially appear when the apparatus is at rest, Figure 14. In this situation, the explosive is resting on a grit particle, producing a gap between the explosive and the glass. When the assembly mass is higher (30 lbs), a pressure circle appears on the video while at rest. In this situation, the applied static load is sufficient to embed the grit into the explosive, bringing the explosive in contact with the glass. Several milliseconds after the test begins, the contact area becomes slightly larger, Table 4. Tests containing pre-embedded particles in the explosive produced a larger contact area as the explosive can now rest on the glass surface. Tests with fewer grit particles also provided a larger contact area to develop because a smaller force was necessary for the grit particles to embed into the explosive.

Table 4. Mid-test high-speed video images of PBX 9501 contact area.

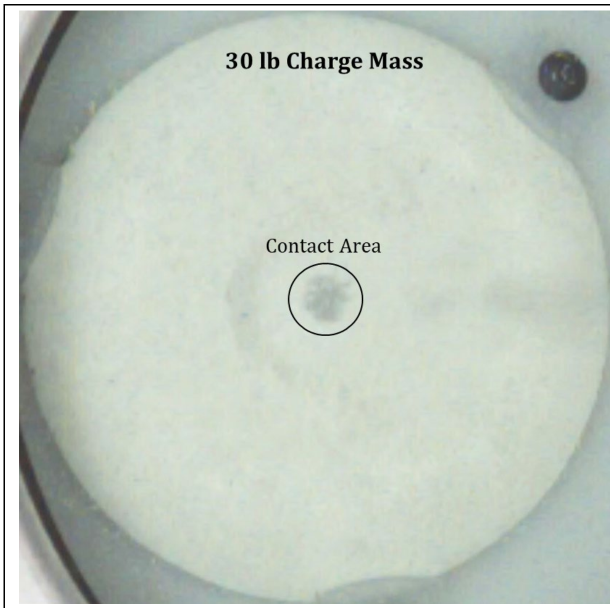


Figure 12. High-speed camera 30 lb charge mass contact area (Slide Test 003).

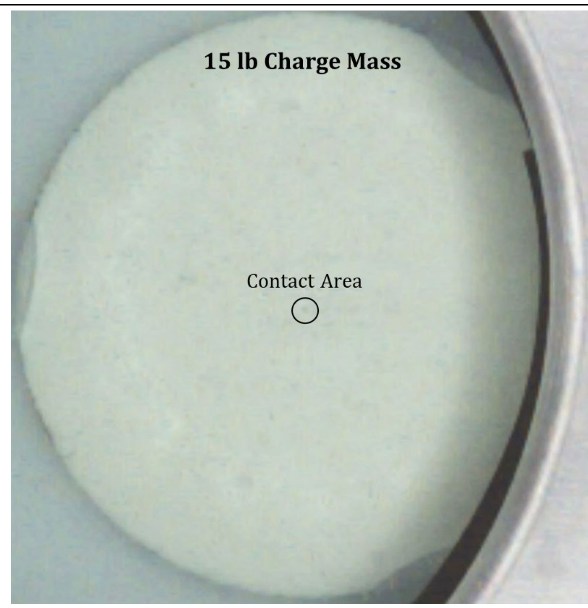


Figure 13. High-speed camera 15 lb charge mass contact area (Slide Test 017).

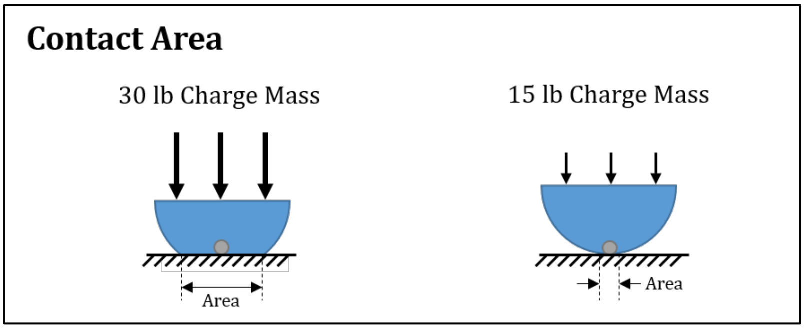


Figure 14. Illustration of contact area dependent of charge mass.

Through the duration of each slide test, we observed a fluctuation in contact area, indicating a varying pressure profile was present at the interface. This variable pressure is also evident in post-mortem examination of the glass and is likely caused by transverse waves transmitting down the length of the connecting rod. This wave is observed in the overview high-speed videos immediately after the hammer strikes the impact pate. Along the path of travel, explosive residue is retained on the glass surface in intermittent patches where the pressure was higher. Gaps exist between these patches where pressure was reduced, Figure 16, and were formed at the trough of the wave where the glass is lower and no longer in contact with the explosive.

Table 5. Images of glass before and after Slide Test 026.

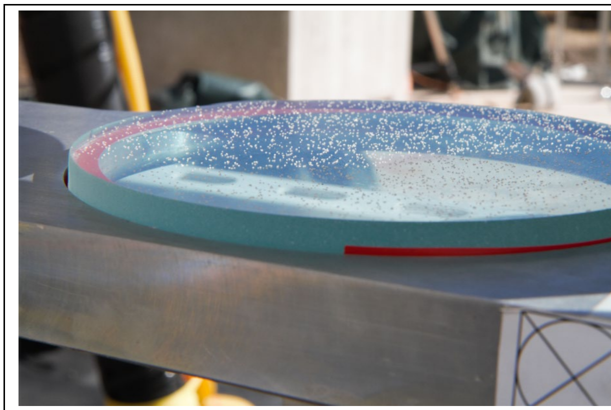
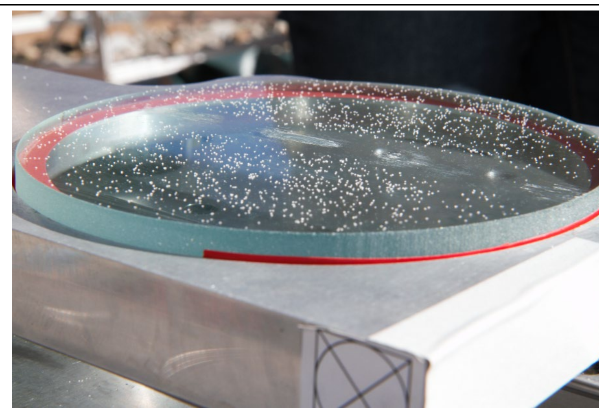
	

Figure 15. Gritty glass pre-test (Slide Test 026).	**Figure 16. Gritty glass post-test (Slide Test 026).**

To characterize the variable pressure effect, an accelerometer was mounted to the glass holder. Figure 17 shows a 4 m s^{-1} velocity impact. The pressure spot area in the high-speed video from Slide Test 005 was analyzed and plotted with the acceleration data from a separate test using mock explosive. The vertical component of this acceleration supports the pressure pulse observation. A negative acceleration feature lasting ~1 ms correlates with the portion of the high-speed video record where the contact spot temporarily vanishes.

The pressure spot area and the acceleration follow a similar wave pattern for the first 7 ms of the test, the time it took for the tests to reach and surpass peak velocity. The waves do not have a correlation in the time thereafter. However, the initial correlation in the first 7 ms of the test endorses accuracy and repeatability within the initial milliseconds of the tests.

Even though the pressure applied to the explosive assembly varies, the duration of the sliding insult during each positive pressure pulse exceeded ~ 2 ms. Therefore, the duration that the HE was in contact with the gritty glass during a single positive pressure pulse exceeds that of the dynamic event observed in Skid Testing (1-2 ms). Ample time for explosive ignition to develop is provided during even a single positive pressure pulse of the overall insult supplied by the Slide Test.

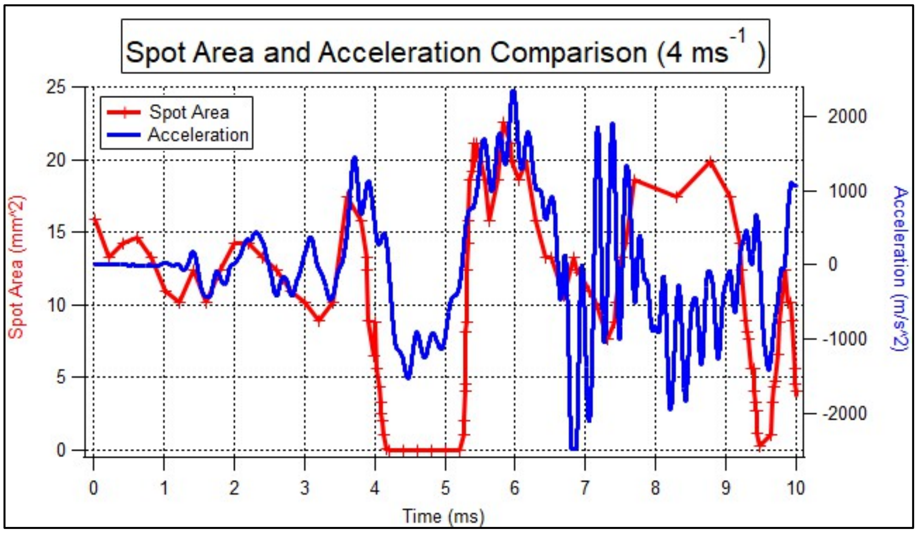


Figure 17. Spot area and acceleration comparison for 4 m s^{-1} slide velocity.

Although no ignition sites were observed in these tests, we hypothesize that some amount of frictional heating was achieved and sub-critical hot spots were formed. Post-mortem examination of grit embedded in the explosive revealed darkened particles that may have been caused by heating that was not visible in the video record. This assumption is backed by evidence of grit particles changing to dark colors in post-test photos, Figure 19.

Table 6. Images of PBX 9501 before and after a Slide Test.

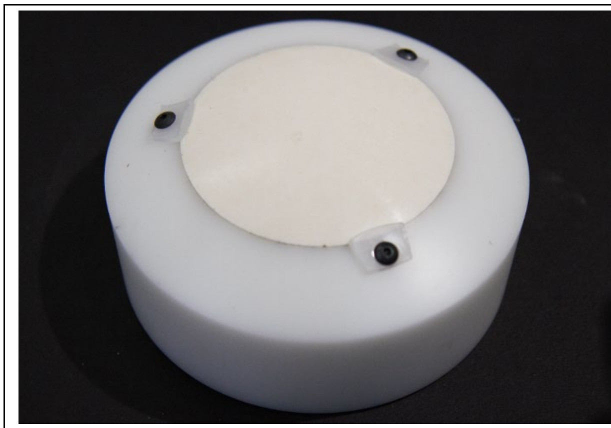
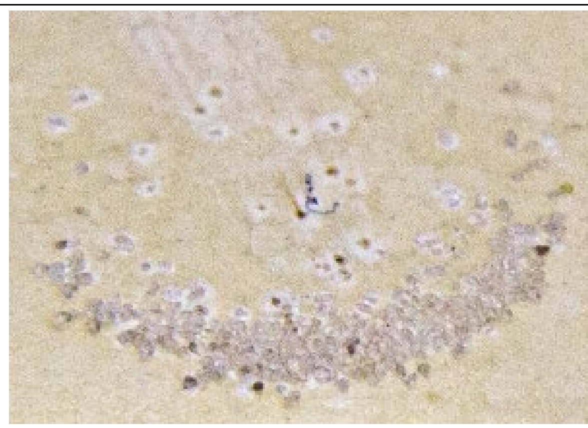
 **Figure 18. PBX 9501 in POM holder pre-test (Slide Test 013).**	 **Figure 19. Close up of post-test 250-500 µm grit in PBX 9501 (Slide Test 027).**

Figure 20 demonstrates the heating of a grit particle as it slides with the explosive across a surface. Although ignition sites were not observed, it is possible that the bright illumination (required to capture video at 150,000fps) was as luminous as an ignition site, interfering with the video contrast. However, because a clear observable ignition threshold was not attained, results of these tests are reported as "no ignition."

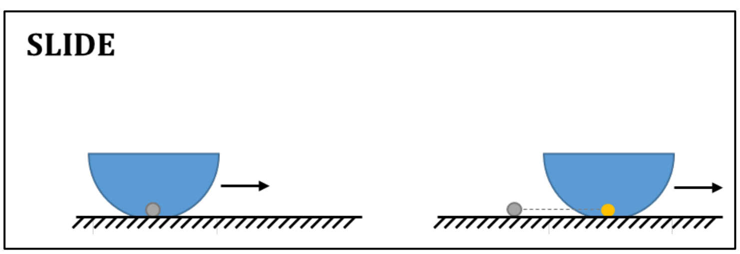


Figure 20. Illustration of Slide Test FY19. It is hypothesized that frictional heating is present, but not enough to ignite the HE.

Table 7 photographs two post-test glass samples. Sample A is from a full glass, 250-500 µm grit Slide Test. Sample B is from a 5 particle, pre embedded pattern, 250-500 µm grit Slide Test. The gouges in the glass demonstrate that grit embedding in the explosive and dragging across the glass, causing some amount of frictional heating to occur.

Table 7. Images of gouges in glass after Slide Tests.

Figure 21. Glass sample A (full 250-500 µm gritty glass)

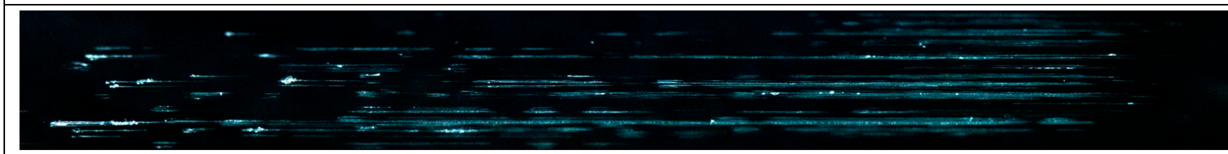


Figure 22. Close-up of glass sample A (full 250-500 µm gritty glass)

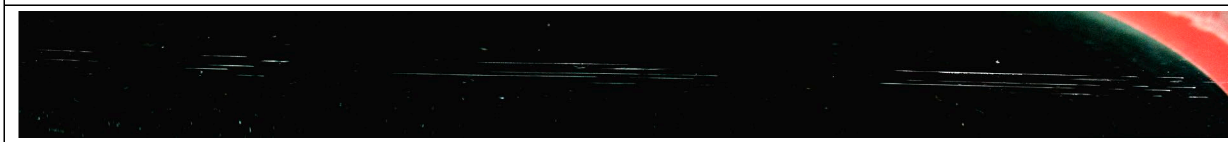


Figure 23. Glass sample B (five 250-500 µm particles pre-embedded in HE).

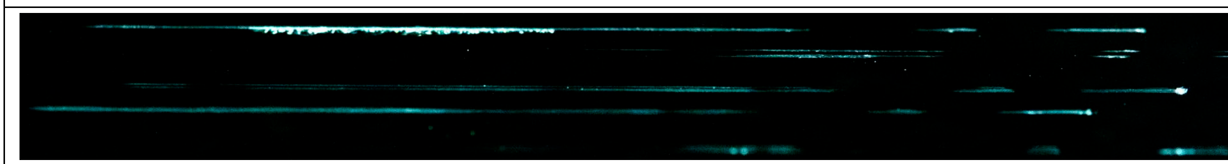


Figure 24. Close-up of glass sample B (five 250-500 µm particles pre-embedded in HE).

Figure 25 and Figure 26 show timelines of grit interaction between the glass and the PBX 9501 in Slide Test 024, showing no signs of ignition. Five pieces of grit were embedded into the PBX 9501 for this test. Although the variable pressure effect is apparent in the high-speed video, a single piece of grit is observed to remain in contact with the glass surface through the duration of the test. Therefore, the grit is again consistently in contact with the glass for a sufficient duration for frictional heating to occur.

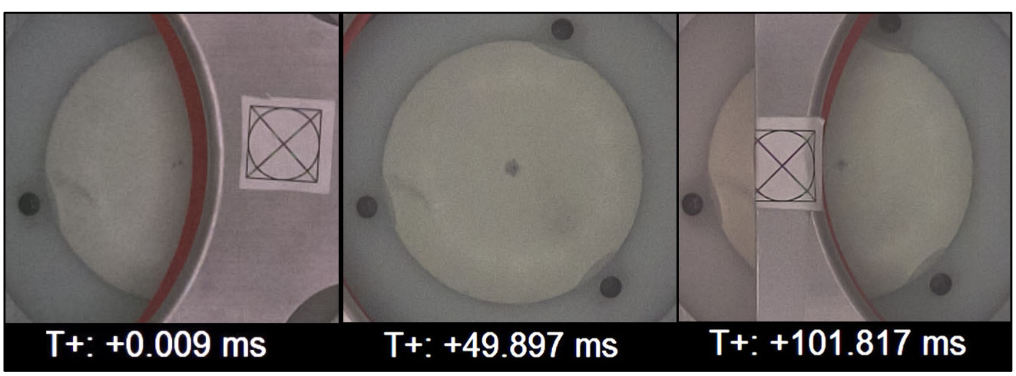


Figure 25. High-speed video frame sequence, viewing through the glass (Slide Test 024).

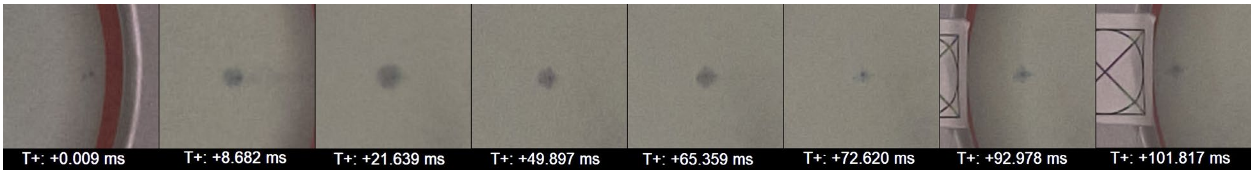


Figure 26. High-speed video frame sequence close up (Slide Test 024).

Our observations suggest a hypothesis for the lack of explosive ignition. It may be that the pressure applied by the static load was insufficient to maintain a gas-tight seal around nascent hot spots and/or the velocities tested were insufficient to create enough frictional heat needed to ignite hot spots.

6. Conclusions

6.1. Summary

Twenty-seven Slide Tests were performed in total, all with PBX 9501. Eighteen tests were performed with a charge mass of ~ 30 lbs and nine tests were performed with a charge mass of ~ 15 lbs. Each charge mass was tested at velocities up to 4 m s^{-1} (low velocities achievable during a handling accident) and a wide range of grit diameters, 75-1000 μm.

No ignitions were observed in Slide Test FY19. The Slide Test data provides evidence that the mass of a main charge, caused to slide on a gritty surface at the low velocities, is insufficient stimulus to heat grit to ignition temperatures. However, the velocity and/or mass threshold at which ignition occurs was not determined. Because no ignitions were observed in any of the tests, we cannot determine which variables dominate the explosive response and to what extent. The absence of any observed ignitions precludes the determination of a safety margin.

6.2. Recommendations for Future Testing

The results from Dyer and Taylor provide evidence that ignition is possible from sliding an explosive charge on a friction surface. Slide Test FY19 does not have enough information to support this due to several limitations: 30 lb charge mass and 4 m s^{-1} velocity. Dyer and Taylor were seeing puffs of smoke with a 100 lb charge mass at unknown velocities (probably ≤ 6 m s^{-1}, the velocity reached in the majority of their published data).

If a threshold is needed to determine a safety margin, the Slide Test apparatus could be redesigned to reach and surpass an ignition threshold from non-impact frictional ignition. This redesign would allow the Slide Test to reach higher velocities with larger charge masses and would be more stable to eliminate the varying pressure profile observed in Slide Test FY19. Further experimentation with the Slide Test would also increase our understanding of the physics behind explosive ignitions.

7. Acknowledgments

We gratefully acknowledge funding from Paul Peterson through the NSR&D program.

8. Data Requests

Videos of the tests as well as various other raw data can be made available on request. Please contact Matt Holmes at mholmes@lanl.gov or 505-665-4107.

9. References

[1] Parker, G. R., Heatwole, E. M., Holmes, M. D., Gunderson, J. A., Novak, A. M., et al., "The Effect of Grit on Frictional Heating During Oblique Impacts with PBX 9501" *Los Alamos National Laboratory Report: LA-UR-13-25703*, 2013.

[2] Dyer, A. S. and Taylor, J. W., "Initiation of Detonation by Friction on a High Explosive Charge" *Proceedings of the 5th Internation Detonation Symposium*, pp. 291-300, Pasadena, CA, 1970.

[3] Holmes, M. D., "Case Penetration; Low-velocity impact ignition of thin metal-cased charges of PBX 9501" *Los Alamos National Laboratory Report: LA-UR-25424*, 2017.

[4] Dobratz, B. M. and Crawford, P. C., "LLNL Explosives Handbook", 1985

[5] Parker, G. R. J., Heatwole, E. M., Holmes, M. D., Vaughan, L. D. and Dickson, P., "The Effect of Grit on Frictional Heating During Oblique Impacts with PBX 9501 Fiscal Year 2014 Update" *Los Alamos National Laboratory Report: LA-UR-14-27843*, 2014.

[6] Pederson, M. N., Parker, G. R. and Holmes, M. D., "Skid Testing FY2019 Report" *Los Alamos National Laboratory Report: LA-UR-19-32669*, 2019.

[7] Parker, G. R., Holmes, M. D., Heatwole, E. M. and Vaughan, L. D., "Oblique Impacts with PBX 9501: Fiscal Year 2015 Skid Testing Results" *Los Alamos National Laboratory Report: LA-UR-15-27394*, 2015.

Appendix A: Slide Test FY 2019 Test Record

Day	Drop # (daily)	Drop # (cumulative)	SRC Shot #	Date	Time of Drop	HE type	Charge Weight (lbs)	Reusing HE?	Drop Angle (box readout, degrees)	Effective Height (box readout)	Nominal Height	Velocity (m/s)	Effective Velocity (m/s)	Impact Surface	Grit Cut	Grit Dia.	Phantom Frame Rate (pps/exposure in us)	Lens Aperature	Still Camera File Names	Light?	Cracking?	Broke Glass?
1	01	001	30120	09/24/19	3:30	PBX 9501	15	N	30.23	3' 0.6"	3'	2.5	N/A	Full Gritty Glass	2	250-500	150000/6.1	11	7219-7232	N	N	N
1	02	002	30121	09/24/19	4:05	PBX 9501	30	N	44.04	6' 0.4"	6'	3.7	N/A	Full Gritty Glass	2	250-500	150000/6.1	11	7233-7277	N	N	N
2	01	003	30122	10/22/19	1:51	PBX 9501	30	N	45.46	6' 4.6"	6' 4.3"	4	4.12	Full Gritty Glass	2	250-500	150000/6.1	11	7278-7286	N	N	N
2	02	004	30123	10/22/19	2:20	PBX 9501	30	N	45.38	6' 4.3"	6' 4.3"	4	4.15	Full Gritty Glass	2	250-500	150000/6.1	11	7287-7293	N	N	N
2	03	005	30124	10/22/19	2:38	PBX 9501	30	N	45.41	6' 4.5"	6' 4.3"	4	4	Half Gritty Glass	2	250-500	150000/6.1	11	7294-7303	N	N	N
2	04	006	30125	10/22/19	2:56	PBX 9501	30	N	45.55	6' 4.8"	6' 4.3"	4	4.09	Half Gritty Glass	2	250-500	150000/6.1	11	7304-7310	N	N	N
2	05	007	30126	10/22/19	3:17	PBX 9501	30	N	45.26	6' 4.0"	6' 4.3"	4	N/A	Single Embedded Grit	2	250-500	150000/6.1	11	7311-7314	N	N	N
2	06	008	30127	10/22/19	3:41	PBX 9501	30	N	45.61	6' 4.7"	6' 4.3"	4	4.12	Single Embedded Grit	2	250-500	150000/6.1	11	7315-7322	N	N	N
3	01	009	30128	10/23/19	11:14	PBX 9501	30	N	45.44	6' 4.2"	6' 4.3"	4	4.03	Four Embedded Grit Pattern	2	250-500	150000/6.1	11	7346-7360	N	N	N
3	02	010	30129	10/23/19	11:34	PBX 9501	30	N	45.38	6' 4.4"	6' 4.3"	4	4.06	Four Embedded Grit Pattern	2	250-500	150000/6.1	11	7361-7374	N	N	N
3	03	011	30130	10/23/19	12:47	PBX 9501	30	N	45.57	6' 4.7"	6' 4.3"	4	4.1	Full Gritty Glass	1	500-1000	150000/6.1	11	7375-7385	N	N	N
3	04	012	30131	10/23/19	1:11	PBX 9501	30	N	45.4	6' 4.4"	6' 4.3"	4	3.99	Full Gritty Glass	3	150-250	150000/6.1	11	7386-7396	N	N	N
3	05	013	30132	10/23/19	1:35	PBX 9501	30	N	45.55	6' 4.8"	6' 4.3"	4	4.01	Full Gritty Glass	4	75-150	150000/6.1	11	7397-7406	N	N	N
3	06	014	30133	10/23/19	1:50	PBX 9501	30	N	33.82	3' 8.1"	3' 8.6"	3	3	Full Gritty Glass	2	250-500	150000/6.1	11	7407-7414	N	N	N
3	07	015	30134	10/23/19	2:07	PBX 9501	30	N	22.78	1' 9.4"	1' 9.3"	2	2.07	Full Gritty Glass	2	250-500	150000/6.1	11	7415-7427	N	N	N
3	08	016	30135	10/23/19	2:22	PBX 9501	30	N	11.92	6.2"	6"	1	1.08	Full Gritty Glass	2	250-500	150000/6.1	11	7428-7433	N	N	N
3	09	017	30136	10/23/19	2:43	PBX 9501	15	N	45.38	6' 4.3"	6' 4.3"	4	4.05	Full Gritty Glass	2	250-500	150000/6.1	11	7436-7440	N	N	N
3	10	018	30137	10/23/19	2:57	PBX 9501	15	N	33.6	3' 8.3"	3' 8.6"	3	2.93	Full Gritty Glass	2	250-500	150000/6.1	11	7441-7445	N	N	N
3	11	019	30138	10/23/19	3:09	PBX 9501	15	N	22.8	1' 9.5"	1' 9.3"	2	2.08	Full Gritty Glass	2	250-500	150000/6.1	11	7446-7454	N	N	N
4	01	020	30139	10/30/19	10:31	PBX 9501	15	N	12.1	6.3"	6"	1	1.52	Full Gritty Glass	2	250-500	150000/6.1	11	7455-7473	N	N	N
4	02	021	30140	10/30/19	10:54	PBX 9501	15	N	45.51	6' 4.7"	6' 4.3"	4	3.98	Full Gritty Glass	1	500-1000	150000/6.1	11	7474-7487	N	N	N
4	03	022	30141	10/30/19	11:10	PBX 9501	15	N	45.35	6' 4.2"	6' 4.3"	4	4.03	Full Gritty Glass	3	150-250	150000/6.1	11	7488-7503	N	N	N
4	04	023	30142	10/30/19	11:26	PBX 9501	15	N	45.26	6' 4.0"	6' 4.3"	4	N/A	Full Gritty Glass	4	75-150	150000/6.1	11	7504-7514	N	N	N
4	05	024	30143	10/30/19	11:45	PBX 9501	15	N	45.33	6' 4.1"	6' 4.3"	4	2.49	Five Embedded Grit Pattern	2	250-500	150000/6.1	11	7515-7525	N	N	N
5	01	025	30144	10/31/19	10:51	PBX 9501	30	N	58.13	9' 8.2"	9' 8.3"	5	4.06	Five Embedded Grit Pattern	2	250-500	150000/6.1	11	7534-7571	N	N	N
5	02	026	30145	10/31/19	11:12	PBX 9501	30	N	58.17	9' 8.1"	9' 8.3"	5	3.65	Full Gritty Glass	2	250-500	150000/6.1	11	7572-7590	N	N	N
5	03	027	30146	10/31/19	11:27	PBX 9501	30	N	72.68	13' 8.7"	13' 8.6"	6	4.08	Full Gritty Glass	2	250-500	150000/6.1	11	7591-7607	N	N	N

Appendix B: CAD Illustrations of Slide Test Apparatus

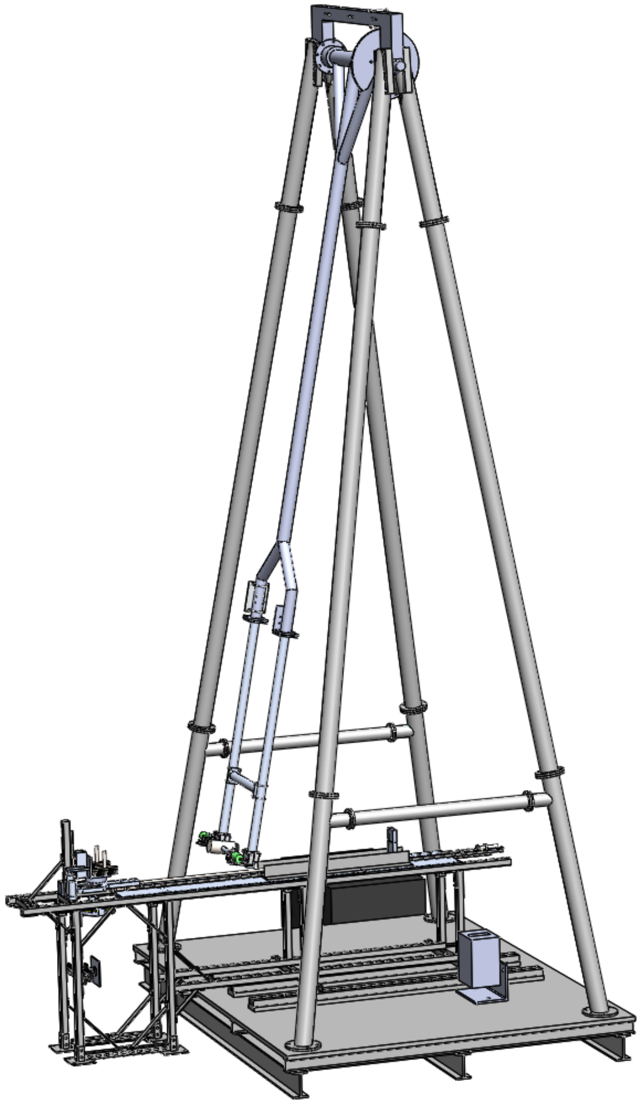


Figure 27. CAD angle view of Slide Test Pendulum assembly.

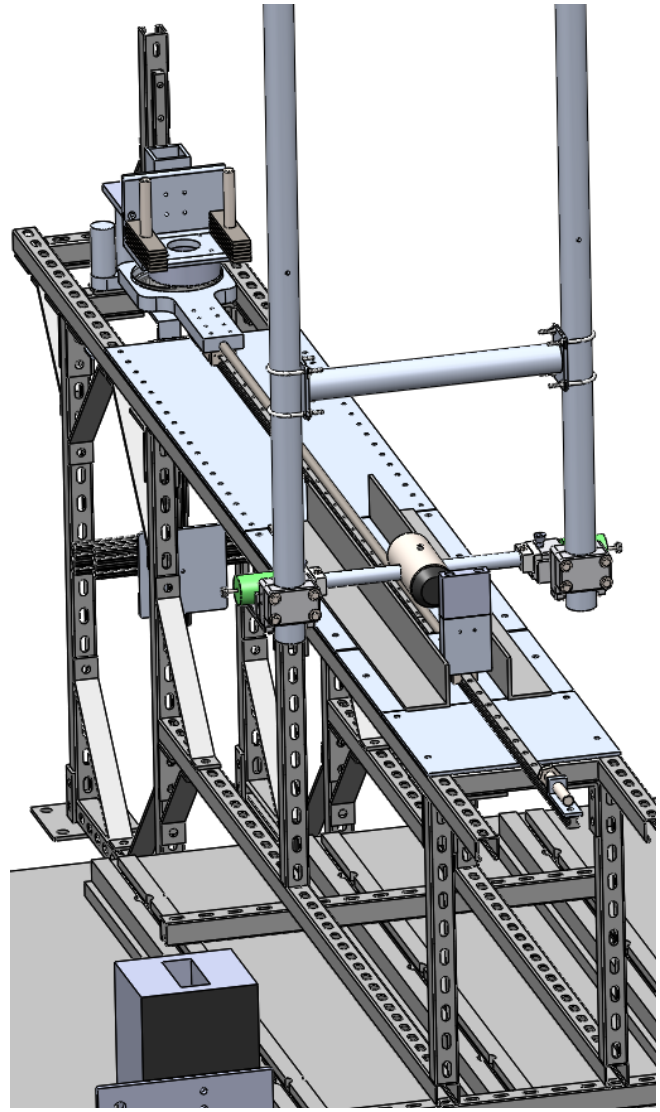


Figure 28. CAD top view of Slide Test assembly.

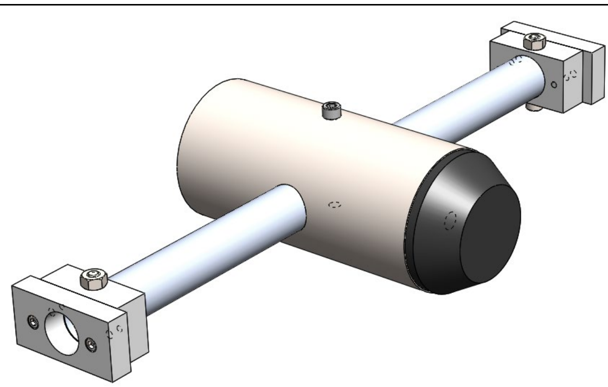


Figure 29. CAD view of impact hammer assembly.

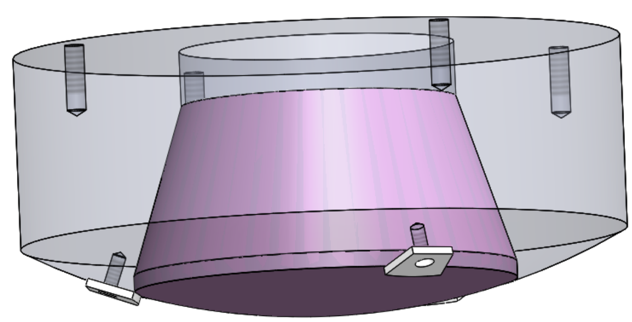


Figure 30. CAD view of HE in POM holder.

Appendix C: Images of Slide Test Apparatus

Figure 31. Slide Test pendulum system overview.

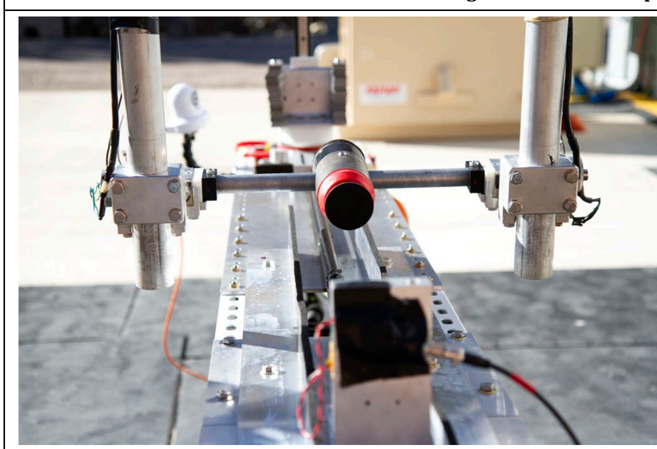


Figure 32. View from behind impact location.

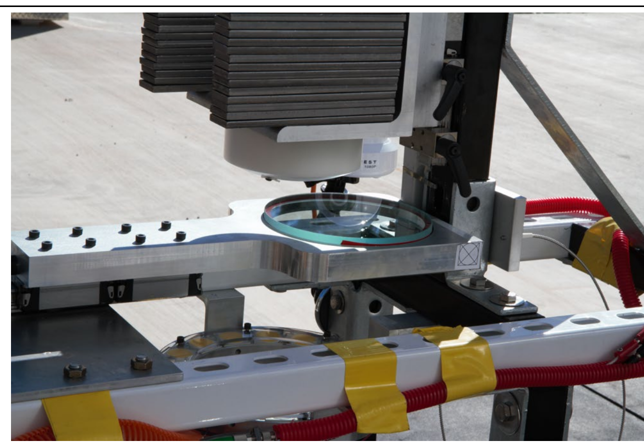


Figure 33. Glass sample in glass holder underneath elevated HE.

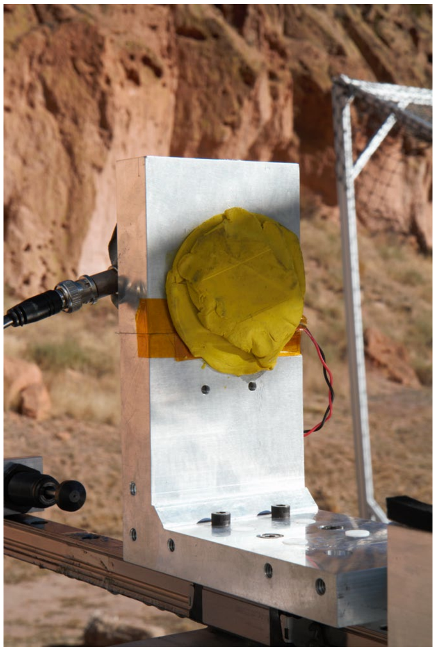


Figure 34. Impact plate with Piezo sensor trigger.

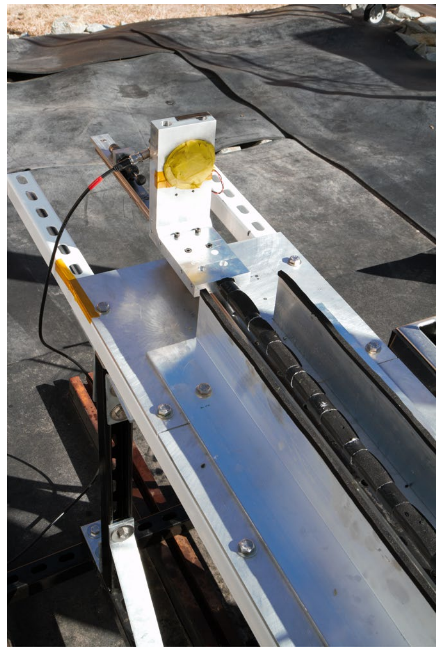


Figure 35. Impact plate and rod connection.

Figure 36. Detailed mirror assembly.

Figure 37. Pneumatically operated arm release latch.

Figure 38. Close up of HE assembly.

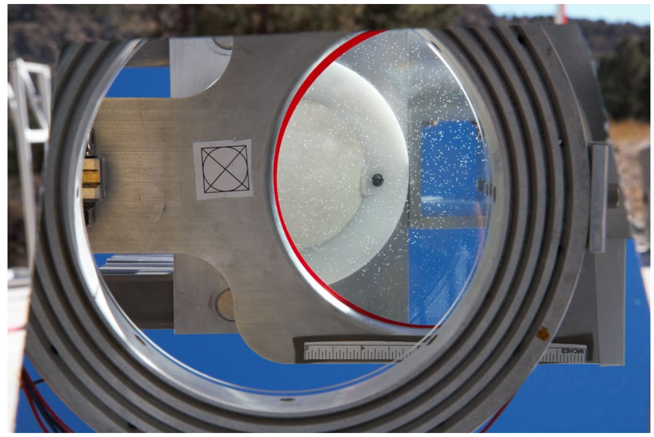


Figure 39. Close up of detailed mirror view.

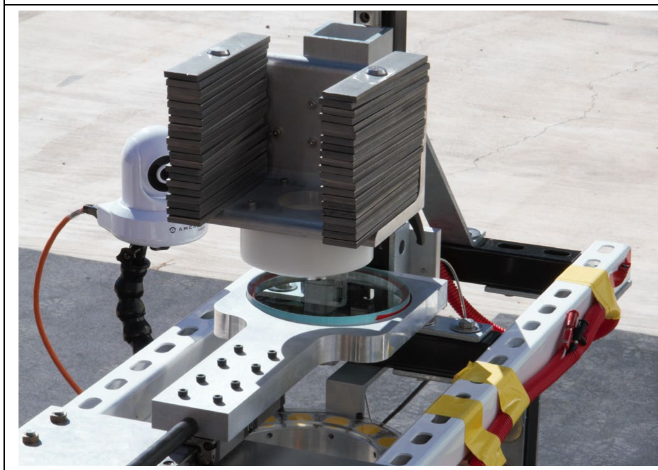


Figure 40. Stacked half-pound weights (30 lb charge mass).

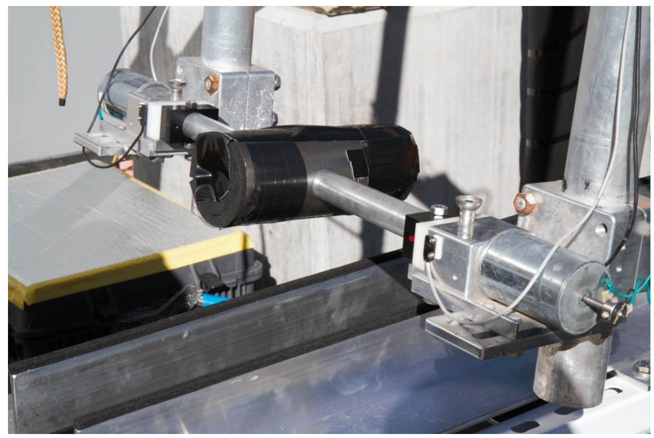


Figure 41. Hammer resting in Pendulum Arm.

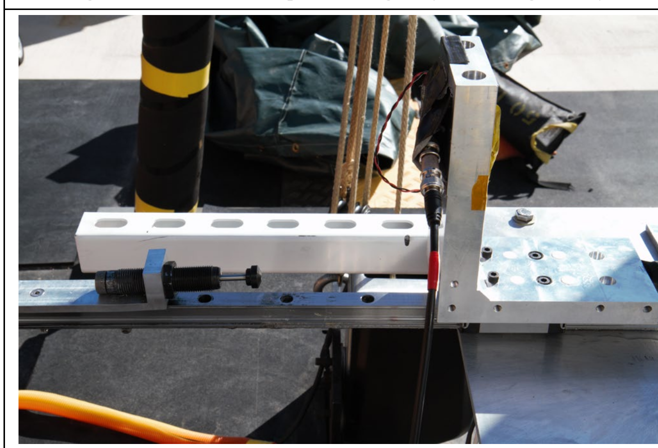


Figure 42. Shock dampener at far end of horizontal rail.

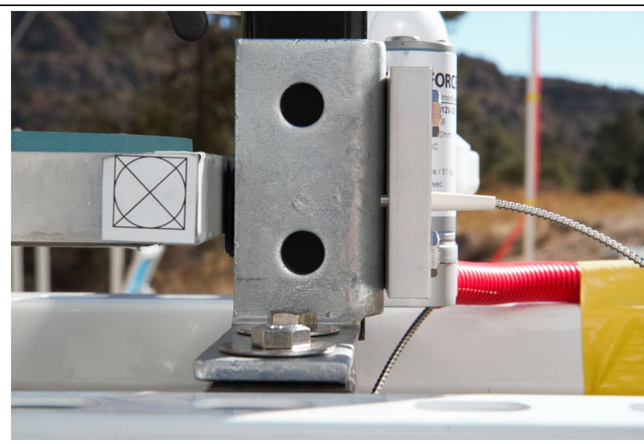


Figure 43. PDV system.